Detecting Earth-like Planets with Radial Velocity Surveys

Stellar surface activity alters the profiles and centroids of the spectral lines measured by radial velocity (RV) planet searches. This jitter varies on timescales from minutes to days and longer and is associated with stellar oscillations, magnetic flux tube evolution, sub-photospheric convection and the surface rotation of sunspots (e.g. Saar and Donahue 1997). The jitter produces a noise floor below which planets are very difficult to detect.

1 Typical RV Jitter Levels

The jitter level depends on the mass, activity and age of the star. Old, inactive G and K dwarfs typically offer the best planet-detection performance, in the 1-5 m/s regime (Saar et al. 2003, Wright 2005). Earlier-type stars generally have jitters in the 4+ m/s range, while active stars often exceed 10 m/s (Wright 2005). Younger stars have far higher jitters – typically 30-40 m/s at 650 MYr age, increasing to 700 m/s at 12 MYr age (Paulson & Yelda 2006).

2 Limits on Terrestrial Planet Detection

Earth induces a 0.06 m/s radial velocity signal in the Sun for typical orbital inclinations. For secure detection of the orbit an individual RV measurement precision of 0.02 m/s is required, which is 100X higher than that expected from a single jitter-limited measurement of a sun-like star (Cumming et al. 2003). RV jitter thus sets stringent limits on low-mass planet detection.

Periodic jitter imposes another limit on the detection of planets in wider orbits. Periodicities in the RV noise can mimic the presence of a planet and thus set ranges of "black-out" periods in which any detected RV signal must be viewed with suspicion (e.g. Queloz et al. 2001, Udry et al. 2005). As RV precision increases and more such non-planetary periodicities are detected the planet parameter space covered by black-out periods will increase, unless the jitter can be very accurately modelled.

3 Overcoming Jitter

A number of strategies for reducing the effects of RV jitter have been examined. It should be noted that there is currently very little available radial-velocity data with precisions better than 1m/s, and so methods for reducing the jitter to levels useful for terrestrial-planet searches cannot yet be tested in detail.

3.1 Selecting Inactive Stars

Most current RV planet surveys select stars for very low activity, thus reducing the typical jitter in their samples to 1-2 m/s (e.g. Udry et al. 2005, Ge et al. 2006, O'Toole et al. 2007). This strategy is unlikely to give further improved sensitivity to much lower mass planets, however, as there are very few stars with <1 m/s jitter (Wright 2005).

3.2 Averaging multiple measurements

The most obvious direct jitter reduction method is to increase the number of measurements and thus average over the jitter noise. This has been demonstrated by the HARPS team to achieve a radial-velocity precision of 0.2 m/s on one star (Lovis et al. 2006), at the cost of a very large amount of observing time. The averaging must be over timescales longer than the stellar rotation period (to remove jitter from sunspots rotating with the stellar surface) and individual observations must be sufficiently long to reduce photon and stellar oscillation noise to acceptable levels (typically 5–15 minutes).

A typical sun-like star with 2 m/s jitter requires 10,000 observations to obtain a single averaged RV measurement with 2 cm/s precision. Sensitivity to the orbit of an Earth-mass planet in the habitable zone of this single star would thus require 10,000–50,000 hours of telescope time, assuming that all other systematic measurement problems can be overcome.

3.3 Jitter Modeling

Saar & Fischer 2000 and Saar et al. 2005 showed that by searching for correlations between spectrally-measured activity and the radial velocity of the star the longer-period jitter could be reduced by 50% in 1/4 of stars. Jitter can be distinguished from a planetary signal by the different line-profile changes it induces to different species; line-bisector measures of changes in stellar line profiles show promise for reducing and detecting jitters (e.g. Melo et al. 2007). Shorter period variations due to sunspots can be similarly reduced for some more active stars (Hatzes 1999, Queloz et al. 2001). It seems likely that these methods will be improved in the future, but no systems have been demonstrated which are reliably capable of reducing jitter to levels below 1 m/s: 0.02 m/s precision remains a distant goal.

4 Other Challenges

Extending RV precision to Earth-like planets requires a far more precise systematic-error calibration than has yet been achieved on-sky. In particular, the instrument's spectral calibration must be stable to cm/s levels over multiple year-long orbits of the planets. Current spectral standards are not stable at the precision required (e.g. Lovis et al. 2006) and so new calibration methods and instruments must be devised and tested.

5 Summary

Jitter sets a noise floor below which planets are very difficult to detect by radial velocity searches. Without precise jitter correction the detection of terrestrial-mass planets in the habitable zones of sun-like stars requires an extremely large amount of telescope time. Active, early-type and young stars show higher levels of jitter and so Earth-like planets are virtually impossible to detect around those stars with current radial velocity methods.

6 References

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